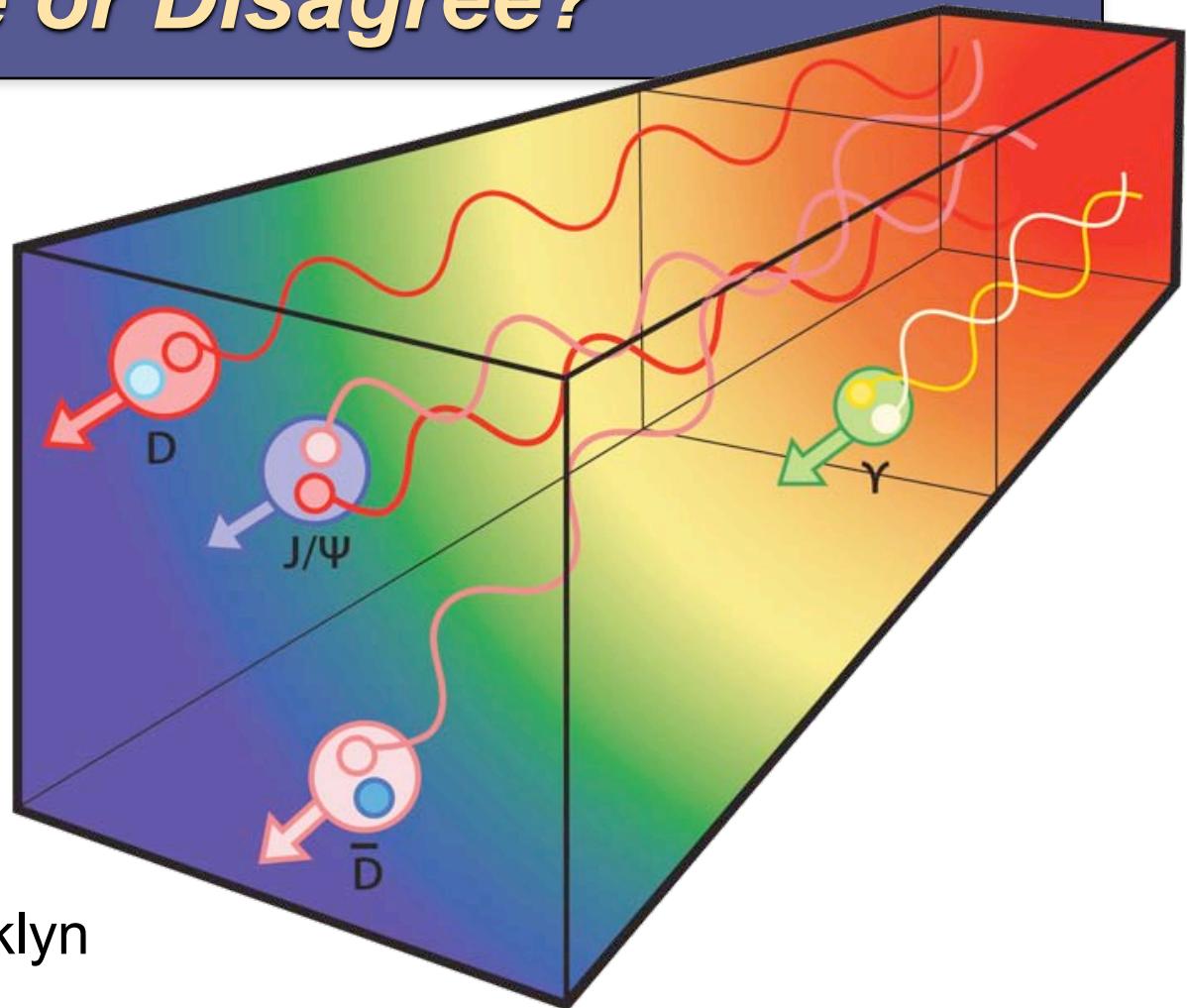


Overview of Potential Models

Do We Agree or Disagree?



Ágnes Mócsy
Pratt Institute, Brooklyn

Pratt

Illustration by Alex Doig (Pratt Institute)

Brief Intro to Potential Models

The interaction between a heavy quark and its antiquark described by a potential $V(r)$

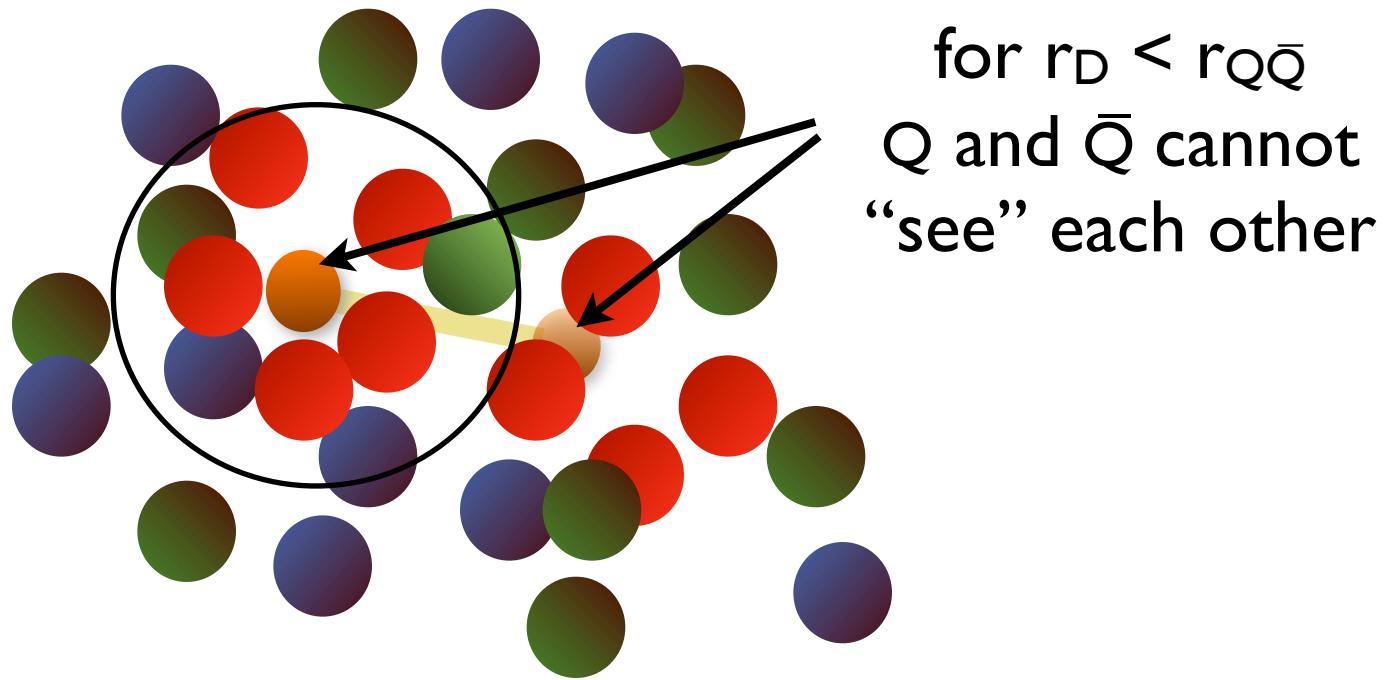


$$\hat{H} = -\frac{\nabla^2}{m_Q} + 2m_Q + V(\mathbf{r})$$

$$E_{\text{bind}, \Psi} = E_\Psi - 2m_Q - \langle V_\infty \rangle$$

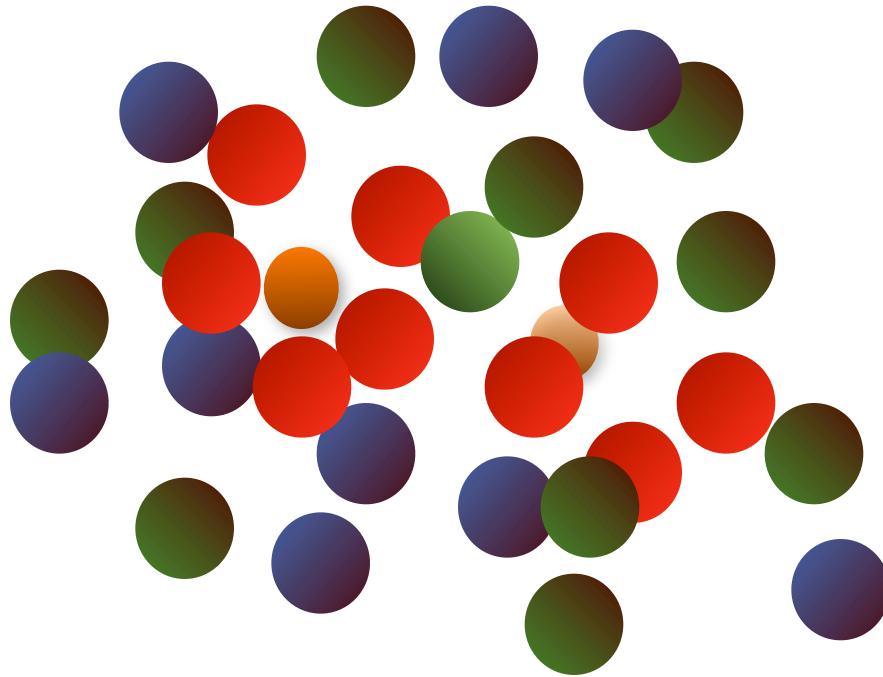
Very successful at T=0

Brief Intro to Potential Models



Assume that all medium effects given
by a T-dependent potential $V(r,T)$

Brief Intro to Potential Models



As a consequence of screening quarkonium states not form
resulting in a suppressed yield

Matsui, Satz, PLB 1986

The QGP Thermometer

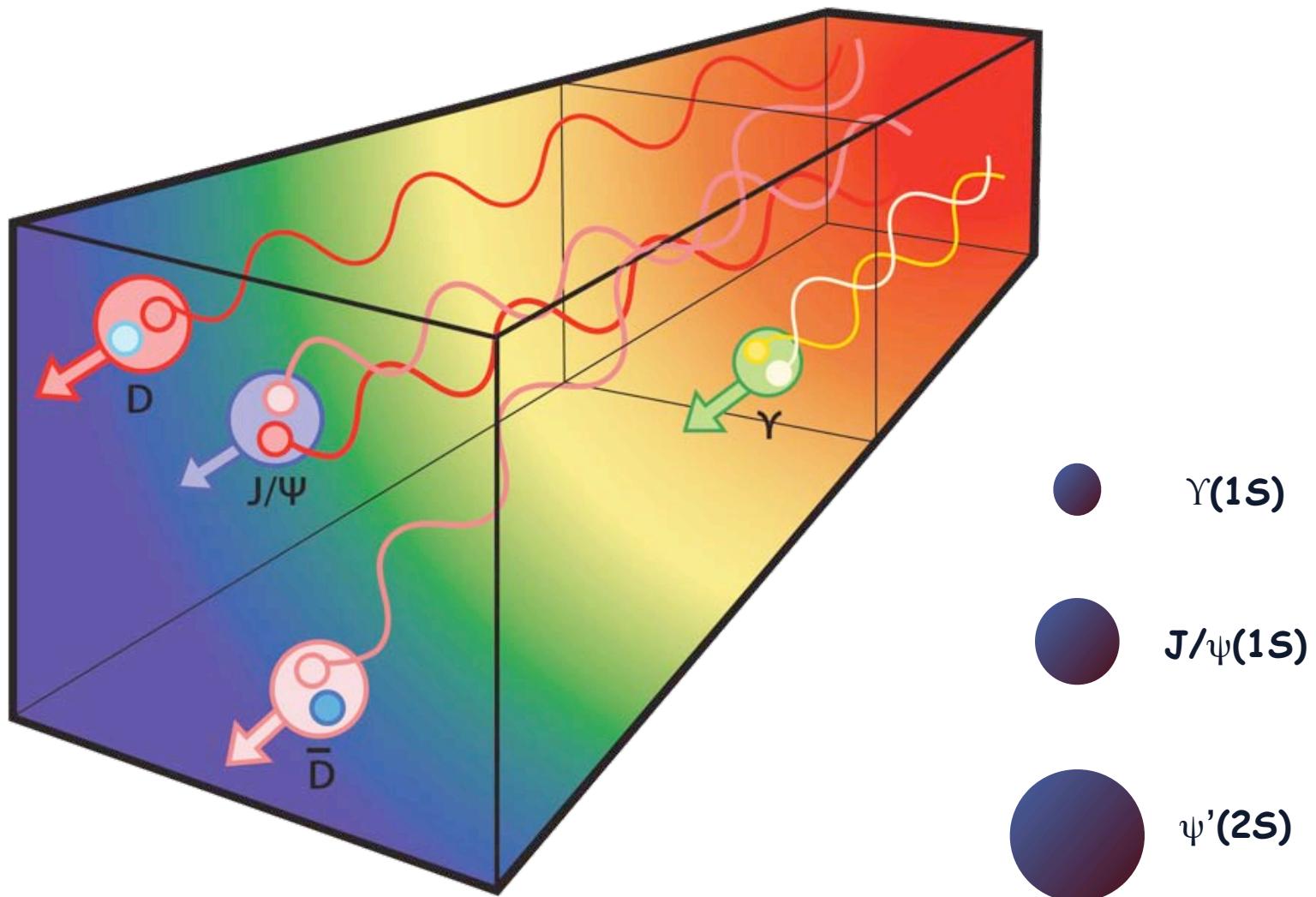
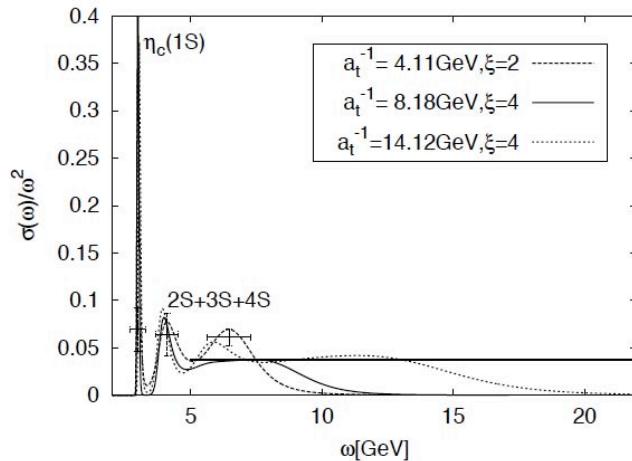


Illustration by Alex Doig (Pratt Institute)

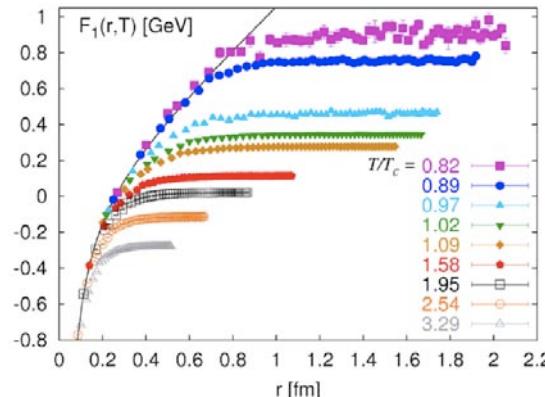
Boost from Lattice QCD

potential model revival

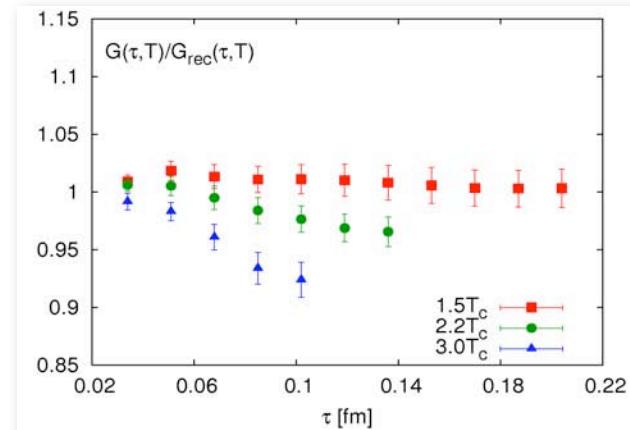
Quarkonium spectral functions



Heavy quark tree energies



Quarkonium correlators



Conflicting messages resulted

Heavy Quarkonia in Quark-Gluon Plasma

Cheuk-Yin Wong

*Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831 and
Department of Physics, University of Tennessee, Knoxville, TN 37996*

(Dated: Februar T-Matrix Approach to Quarkonium Correlation Functions in the QGP

Using the color-singlet free energy F_1 and total int
for Quarkonia in the deconfined phase: effective potentials and
wa
a s
fro
ou
be
ap
cha
the
lattice correlators

W.M. Alberico,¹ A. Beraudo,^{1,2} A. De Pace,¹ and A. Molinari¹

¹*Dipartimento di Fisica Teorica dell'Università di Torino and
Istituto Nazionale di Fisica Nucleare, Sezione di Torino,
via P.Giuria 1, I-10125 Torino, Italy*

Can quarkonia survive deconfinement?

Ágnes Mócsy

RIKEN-BNL Research Center, Brookhaven National Laboratory, Upton NY 11973, USA

Péter Petreczky

*RIKEN-BNL Research Center and Physics Department,
Brookhaven National Laboratory, Upton NY 11973, USA*

We study quarkonium correlators and spectral functions at zero and finite t with only heavy quarks using potential models combined with perturbative QCD this approach can describe the quarkonium correlation function at zero temperat screened potentials based on lattice calculations of the static quark-antiquark free spectral functions at finite temperature. We find that all quarkonium states, of the $1S$ bottomonium, dissolve in the deconfined phase at temperatures sm contradiction with the conclusions of most studies. Despite this, the temper the quarkonium correlation functions could be used to determine well below. We also find that even in the absence of resonances the spectral function at h significantly enhanced over the spectral function corresponding to free quark ant

J/Psi Melts just above T_c

controversy

J/Psi Survives to 2Tc

D. Cabrera and R. Rapp

*Cyclotron Institute and Physics Department,
University, College Station, Texas 77843-3366, U.S.A.*
(Dated: February 2, 2008)

Abstract

heavy quarkonium states with temperature in a Quark Gluon Plasma (QGP) $Q\bar{Q}$ T -matrix within a reduced Bethe-Salpeter equation in both S - and lting interaction kernel is extracted from recent finite-temperature QCD lattice ergy of a $Q\bar{Q}$ pair. The bound states are found to gradually move above the rapidly dissolve in the hot system. The T -matrix approach is particularly lanisms as it provides a unified treatment of bound and scattering states the transition to the (perturbative) continuum. We apply the T -matrix ions as well as pertinent Euclidean-time correlation functions which are

Color Screening Melts Quarkonium

Ágnes Mócsy

RIKEN-BNL Research Center, Brookhaven National Laboratory, Upton NY 11973, USA

Péter Petreczky

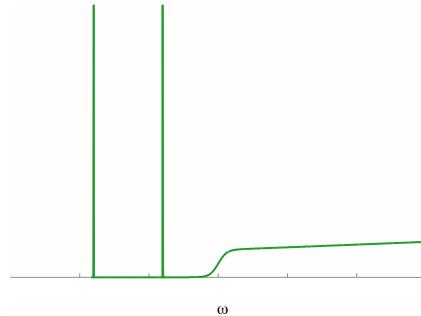
Physics Department, Brookhaven National Laboratory, Upton NY 11973, USA

We calculate quarkonium spectral functions in a quark-gluon plasma using a potential model based on full QCD lattice calculations of the free energy of static quark-antiquark pair. We estimate the binding energy and the thermal width of different quarkonium states. The estimated upper limit for the dissociation temperatures is considerably lower than the ones suggested in the recent literature.

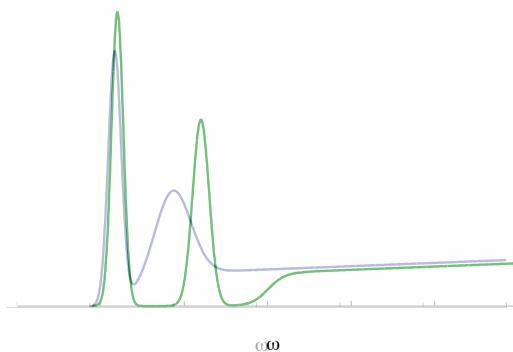
New Type of Potential Models

calculate spectral functions

provides unified treatment of bound states, continuum and threshold



bound state for non-zero E_{bin}



No peak no bound state
 $E_{\text{bin}} = 0$ condition is an overkill

New Type of Potential Models

calculate spectral functions

- T-matrix

Rapp, Mannarelli, Cabrera

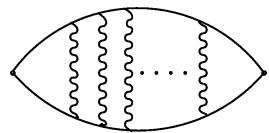
- non-relativistic Green's function

Mocsy, Petreczky

Non-relativistic Green's function

Energies below and near continuum threshold

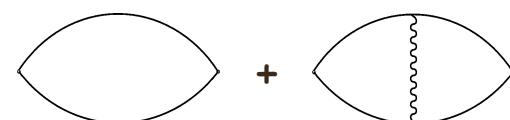
$$\left[-\frac{1}{m} \nabla^2 + V(\vec{r}) + E \right] G^{NR}(\vec{r}, \vec{r}', E) = \delta^3(\vec{r} - \vec{r}')$$



+

pQCD

Well above threshold



$$\sigma_{pert} \cong \omega^2 \frac{3}{8\pi} \left(1 + \frac{11}{3\pi} \alpha_s \right)$$

Medium effects important near threshold

$$\sigma(E) = \frac{2N_c}{\pi} \text{Im} G^{NR}(\vec{r}, \vec{r}', E) \Big|_{\vec{r}=\vec{r}'=0}$$

S-wave

$$\sigma(E) = \frac{2N_c}{\pi} \frac{1}{m^2} \vec{\nabla} \cdot \vec{\nabla}' \text{Im} G^{NR}(\vec{r}, \vec{r}', E) \Big|_{\vec{r}=\vec{r}'=0}$$

P-wave

First in vector channel: Strassler, Peskin, PRD(1991)

Input: Heavy Quark Potential $V(r,T)$

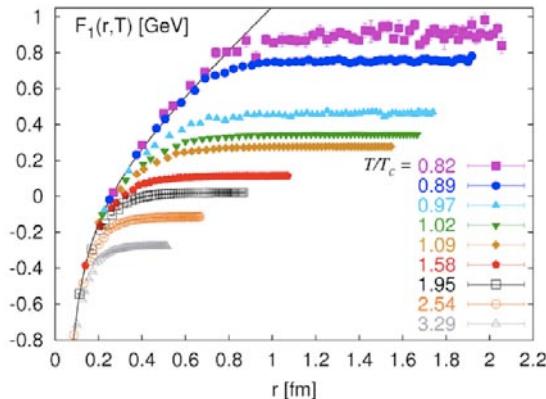
Customary assumption: all medium effects accounted for as a T-dependent screened potential

1) Screened Cornell

$$F(r, T) = -\frac{\alpha}{r} \exp(-r m_D) + \frac{\sigma}{m_D} [1 - \exp(-r m_D)]$$

Re V

2) Lattice-based



F1? U1?

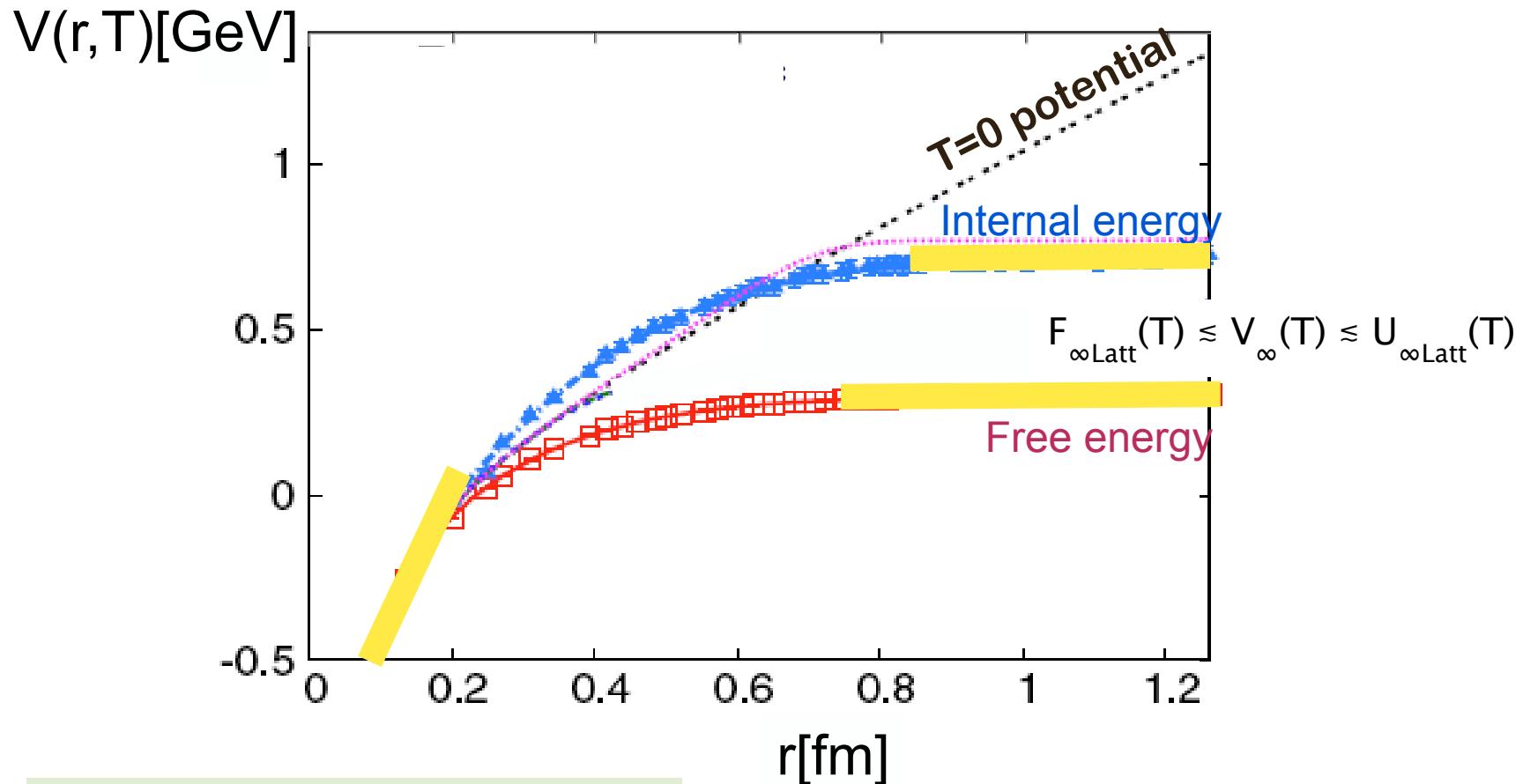
Their combo? Most confining?

Re V

3) Derived from QCD

Re V and Im V

Lattice-based Potentials

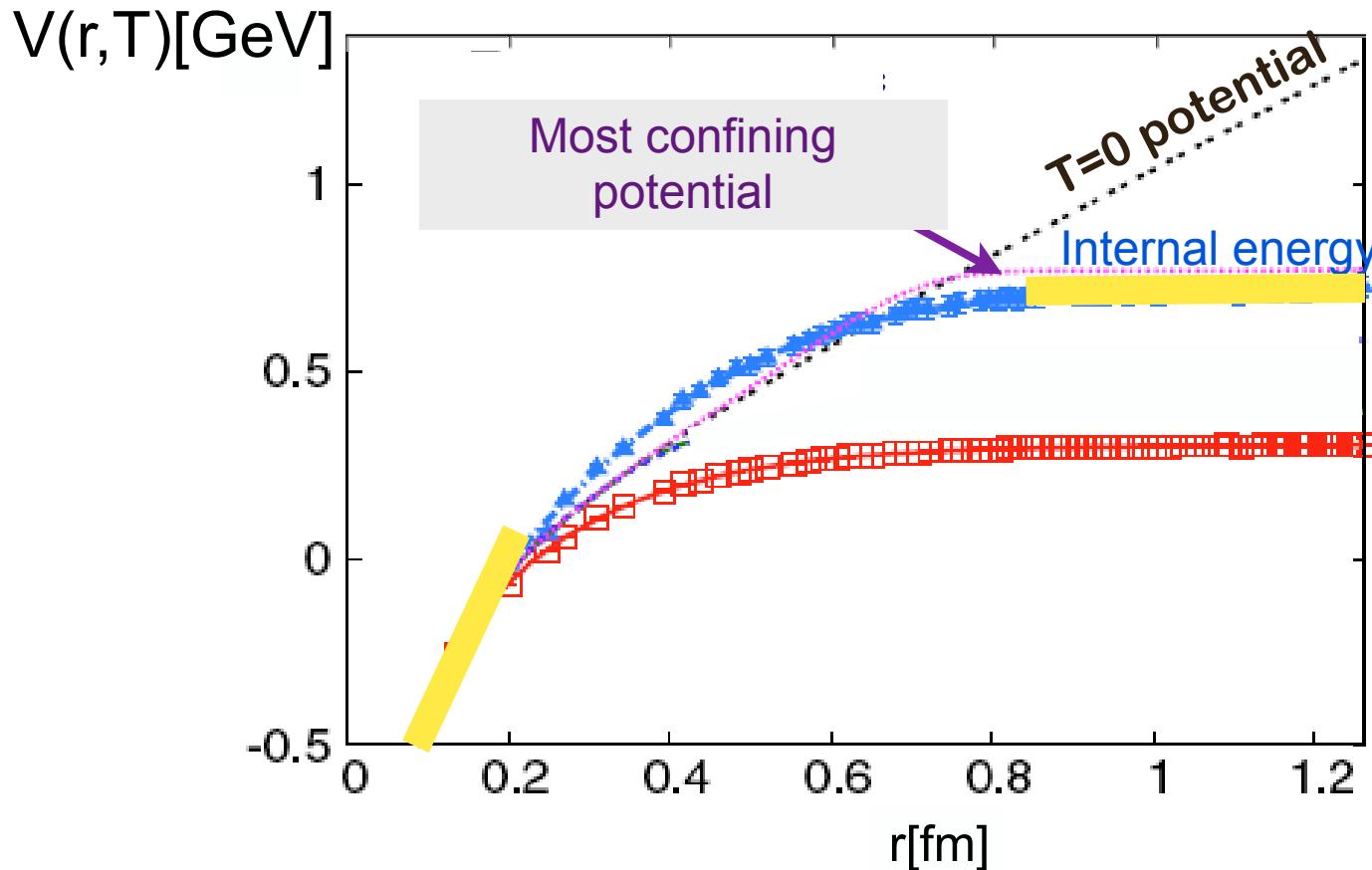


Short distance: T=0 potential
Large distance: constrained domain
Intermediate distance: we don't know

Shortcoming:
ad hoc

Lattice-based Potentials

Upper Limits

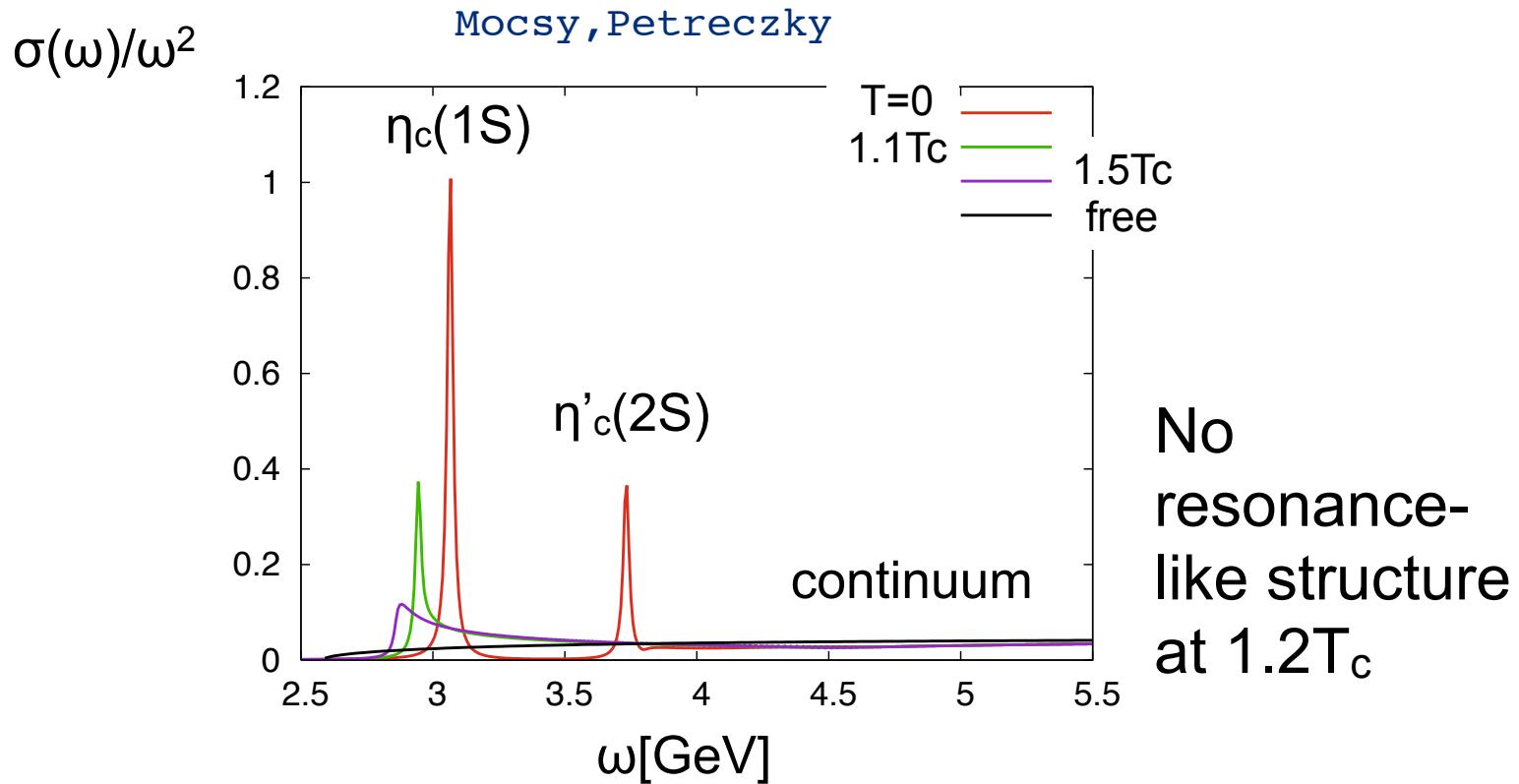


Internal energy
Cabrera, Rapp

&
Most confining potential
Mocsy, Petreczky

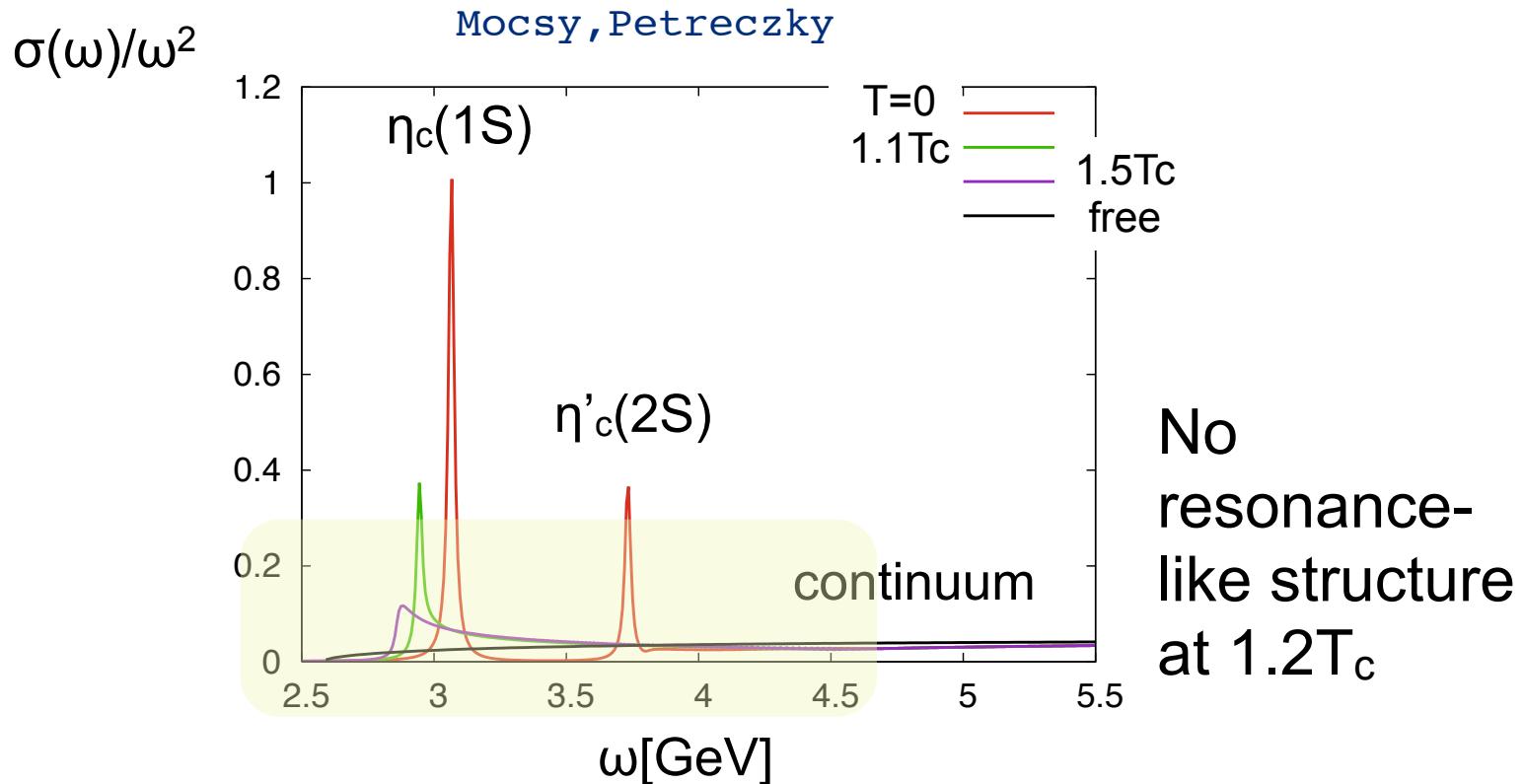
Charmonium Spectral Function using the most confining potential

Nf=2+1 data



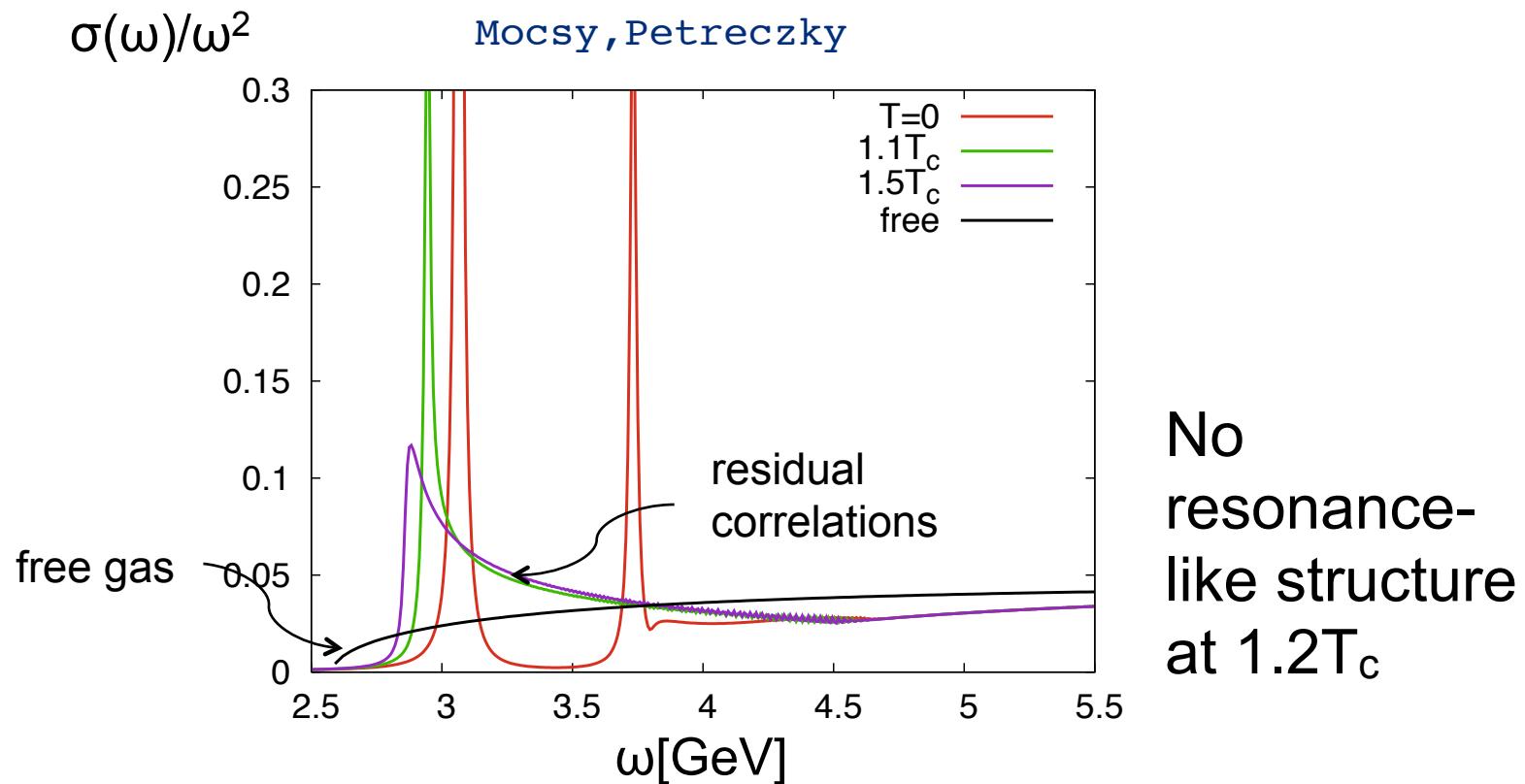
Charmonium Spectral Function using the most confining potential

Nf=2+1 data



Charmonium Spectral Function using the most confining potential

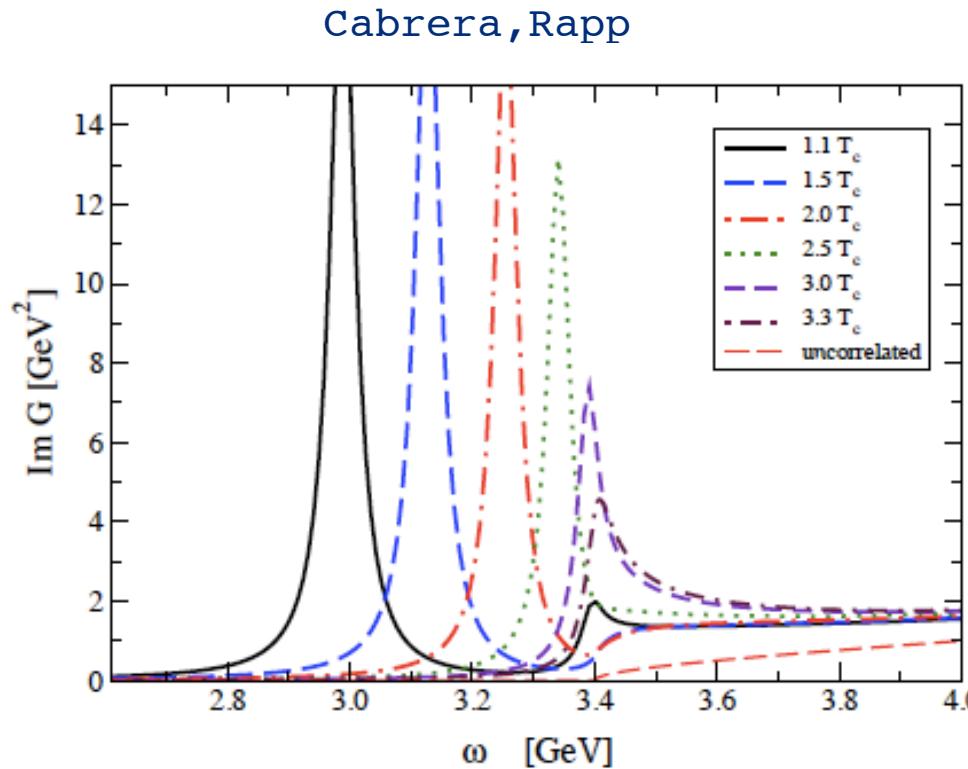
Nf=2+1 data



- Threshold enhancement up to high T indicating correlation between c and cbar
- Binding energy decreases

Charmonium Spectral Function using the internal energy

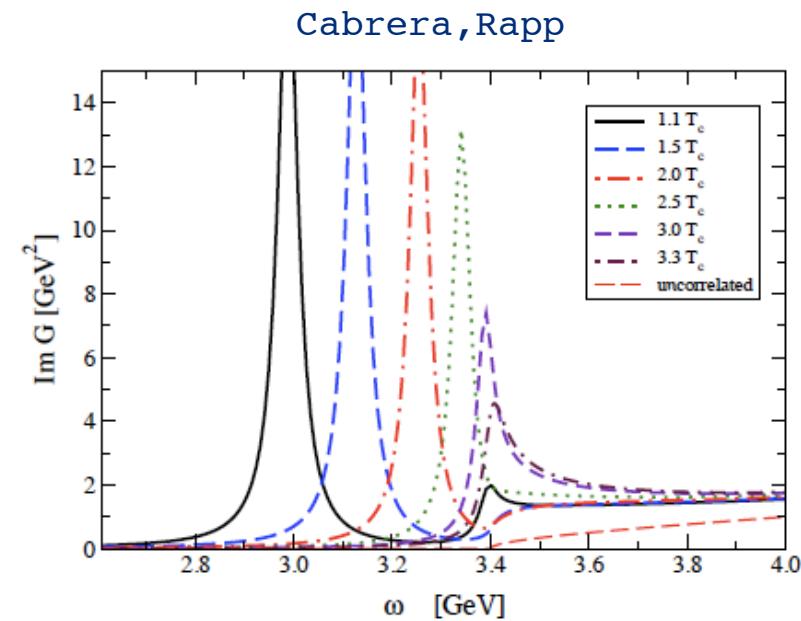
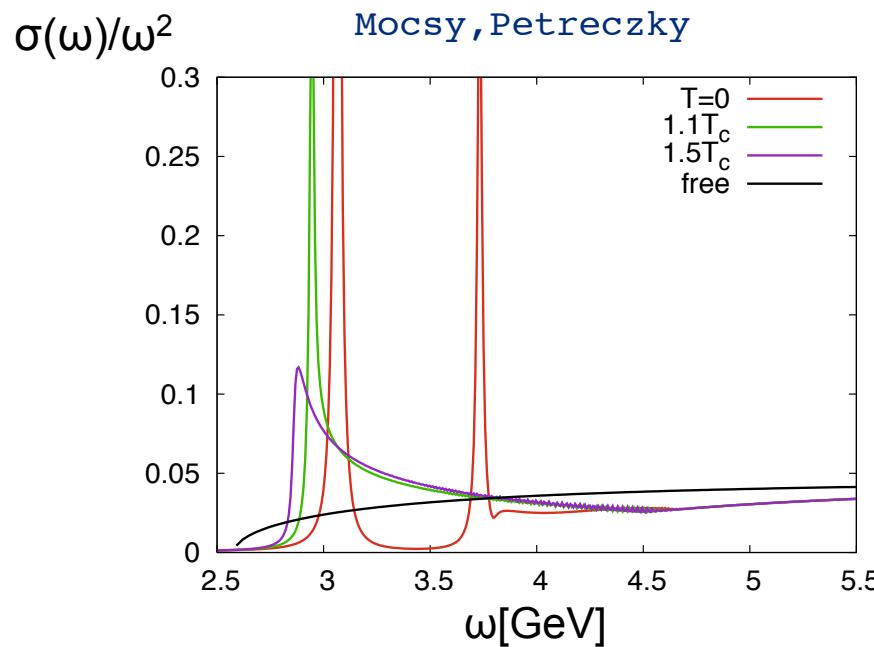
Nf=3 data



Resonance-
like structure
at $2T_c$

- Threshold enhancement up to high T indicating correlation between c and cbar
- Binding energy decreases

Charmonium Spectral Functions

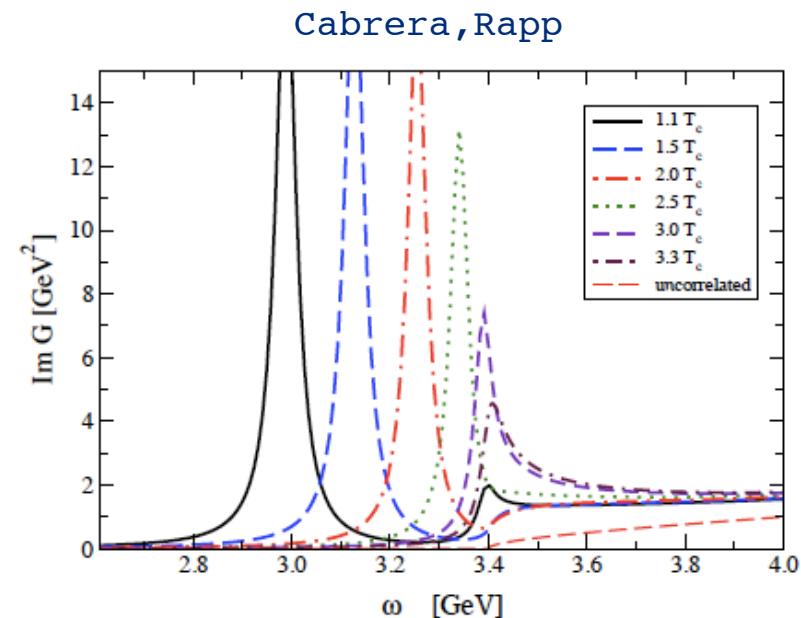
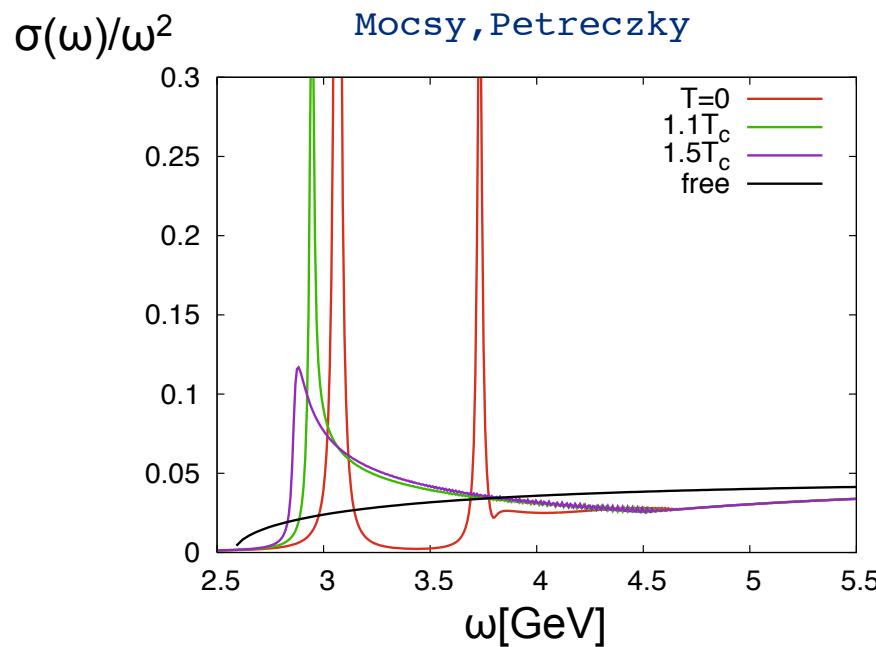


Agree

- Threshold enhancement up to high T indicating correlation between c and cbar
- Binding energy decreases

For all the states

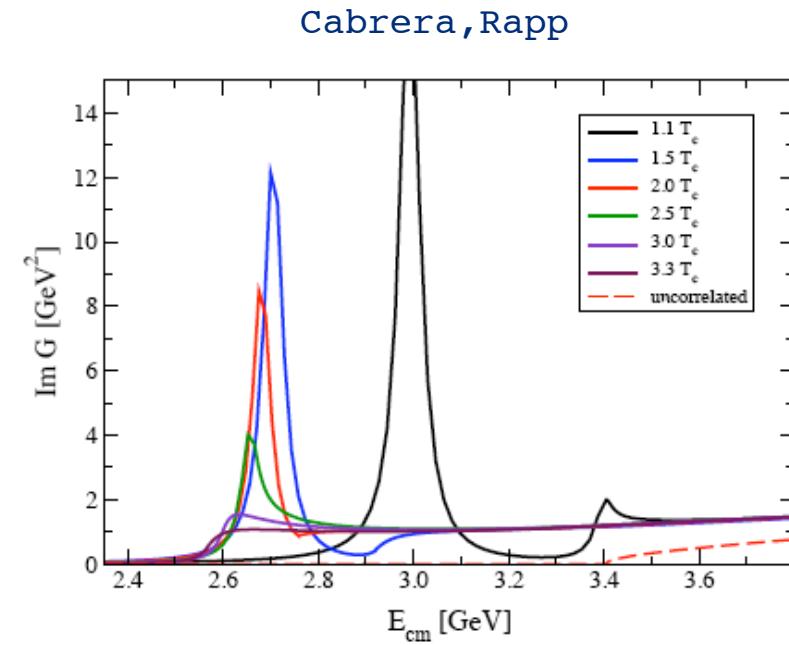
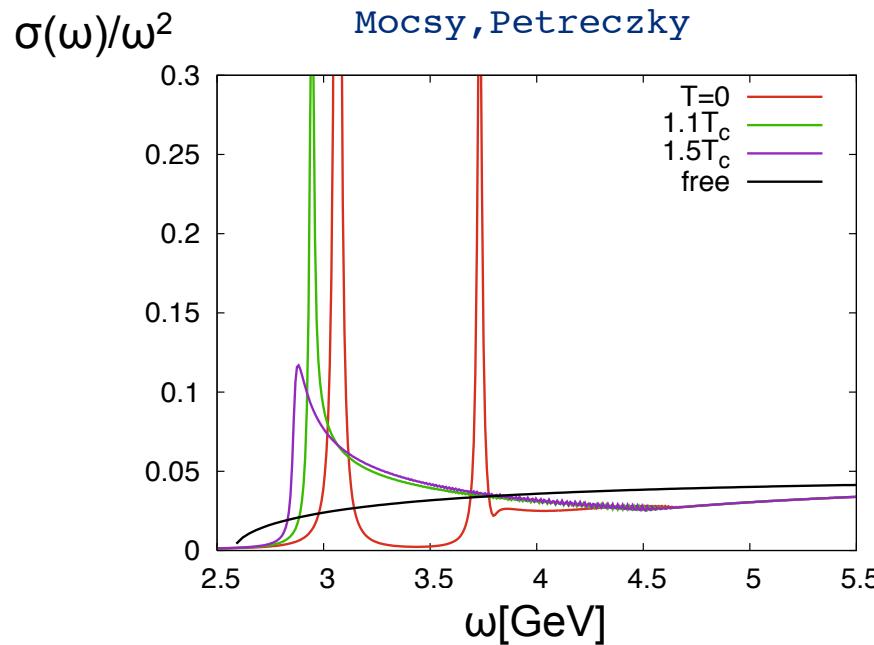
Charmonium Spectral Functions



Disagree

Potential: Most confining potential vs. Internal energy
Lattice data: Nf=2+1 vs. Nf=3

Notes on the Quark Mass

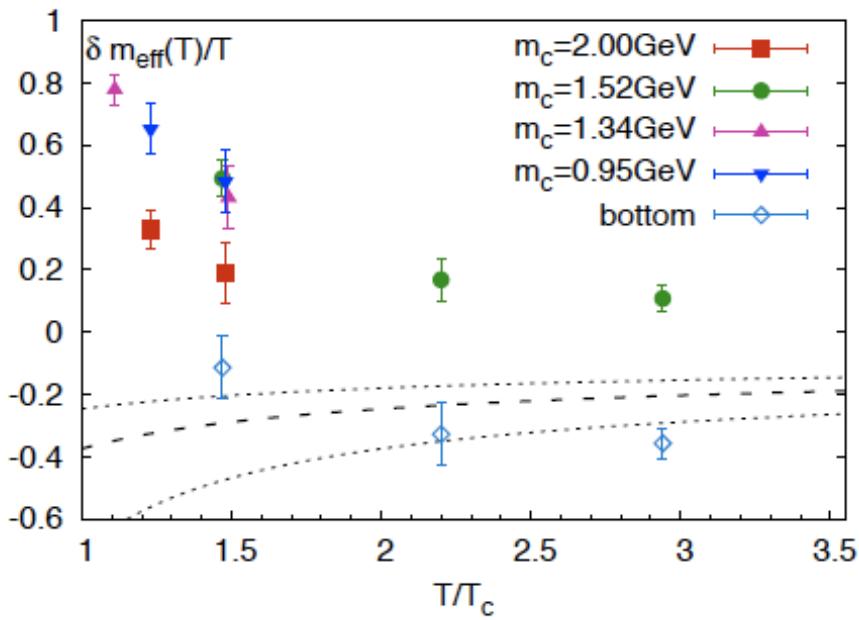


Disagree

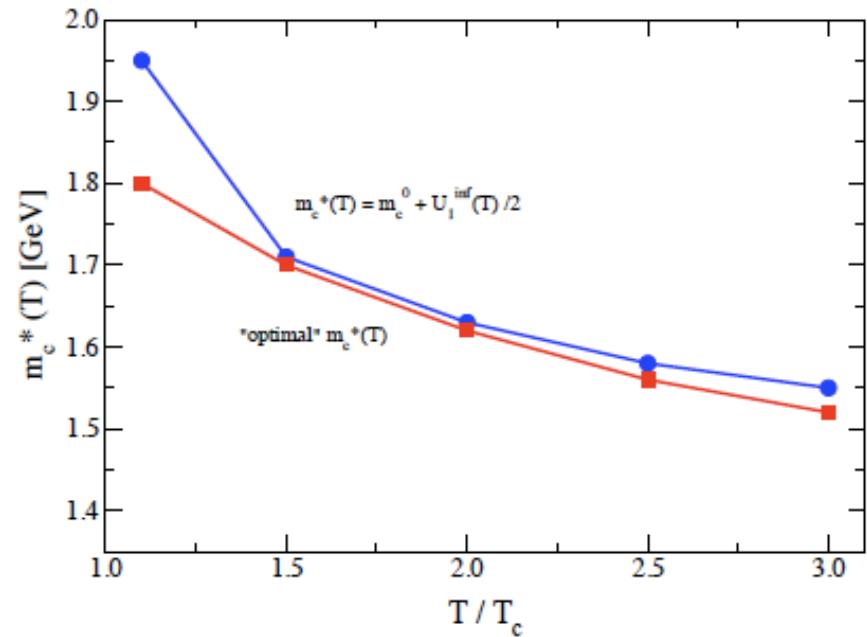
Quark mass: mq vs. $mq(T)$

Notes on the Quark Mass

Datta, Petreczky



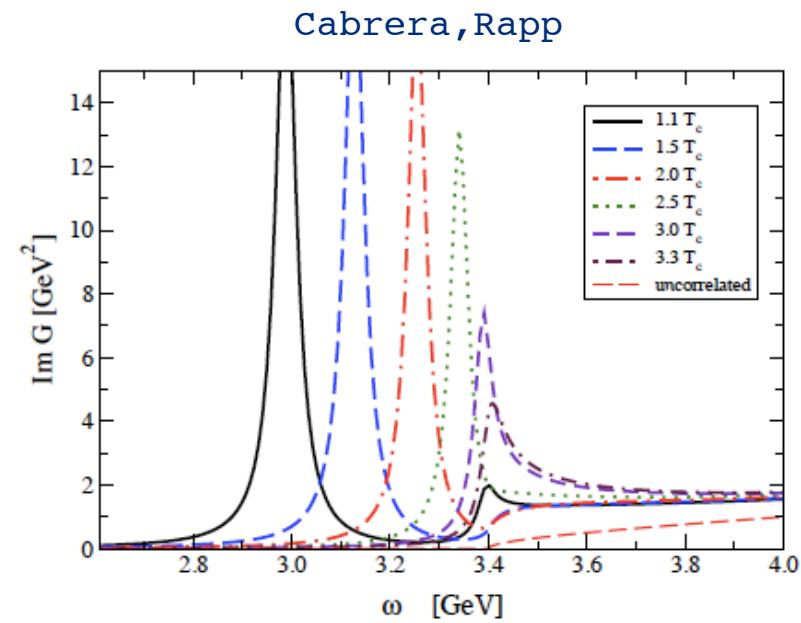
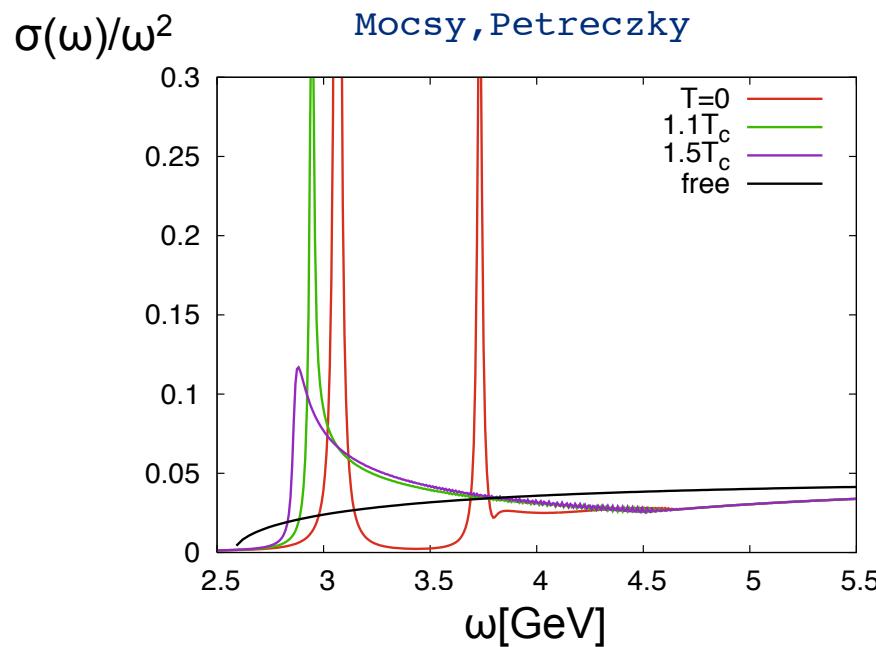
Cabrera, Rapp



also: small thermal corrections to quark mass from quark spectral function calculation on the lattice

Kitazawa, Karsch

Charmonium Spectral Functions



Disagree

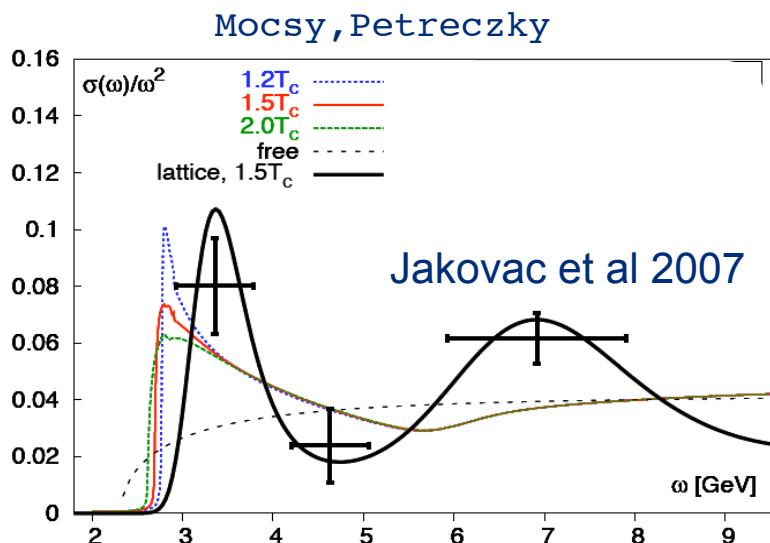
In the statements: Jpsi dissociates by $1.2T_c$ vs by $2.5 - 3T_c$

Agree

Agreement with lattice spectral functions ?!

Compared to Lattice Spectral Functions

“Lattice data is consistent with no bound state but threshold enhancement”



“J/psi survives above $2T_c$, in agreement with lattice spectral functions”

Cabrera, Rapp

Lattice peak: large width ~ 1 GeV
large uncertainties
details cannot be resolved

This comparison will not be resolved in the near future

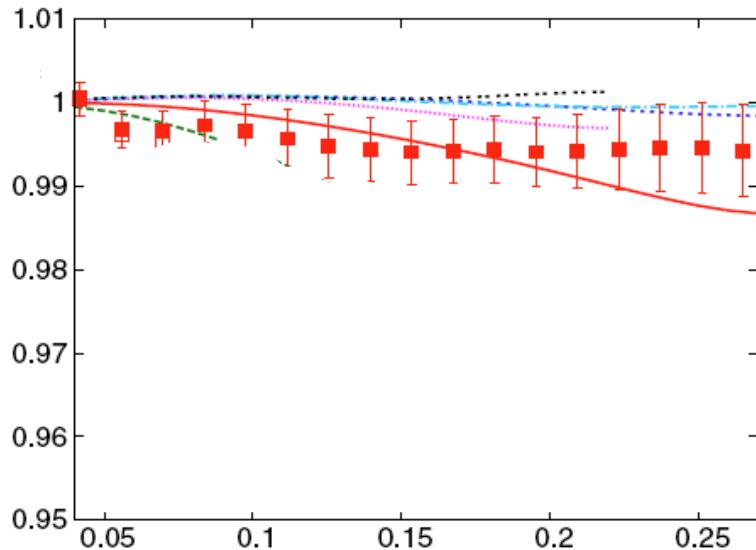
Compare to Lattice Correlators

Pseudoscalar Charmonium

$$G(\tau, T) = \int \sigma(\omega, T) K(\tau, \omega, T) d\omega$$

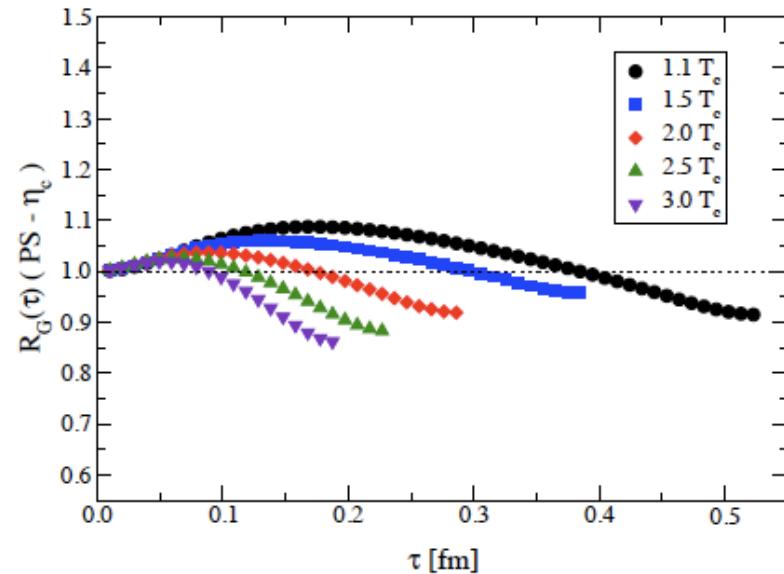
$$G_{rec}(\tau, T) = \int \sigma(\omega, T=0) K(\tau, \omega, T) d\omega$$

Mocsy, Petreczky



1-2% agreement

Cabrera, Rapp



20% agreement

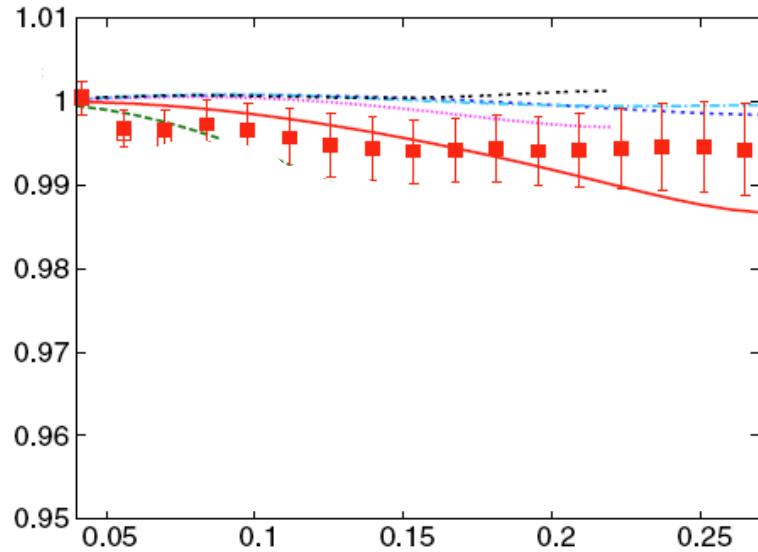
But disagreement in the interpretation of the lattice data

Note: true for any lattice-based potential, except free energy

Compare to Lattice Correlators

Pseudoscalar Charmonium

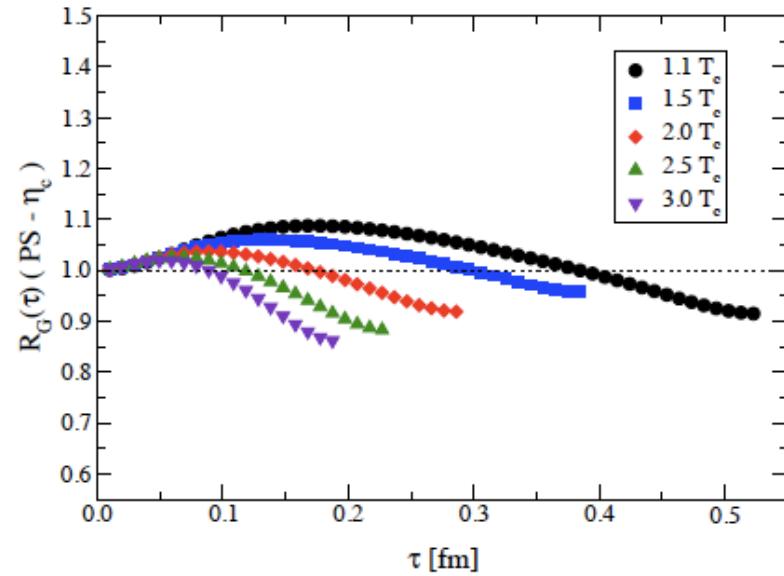
$$\frac{G(\tau, T) = \int \sigma(\omega, T) K(\tau, \omega, T) d\omega}{G_{rec}(\tau, T) = \int \sigma(\omega, T=0) K(\tau, \omega, T) d\omega}$$



1-2% agreement

*Threshold enhancement compensates
for lack of bound states*

Mocsy, Petreczky

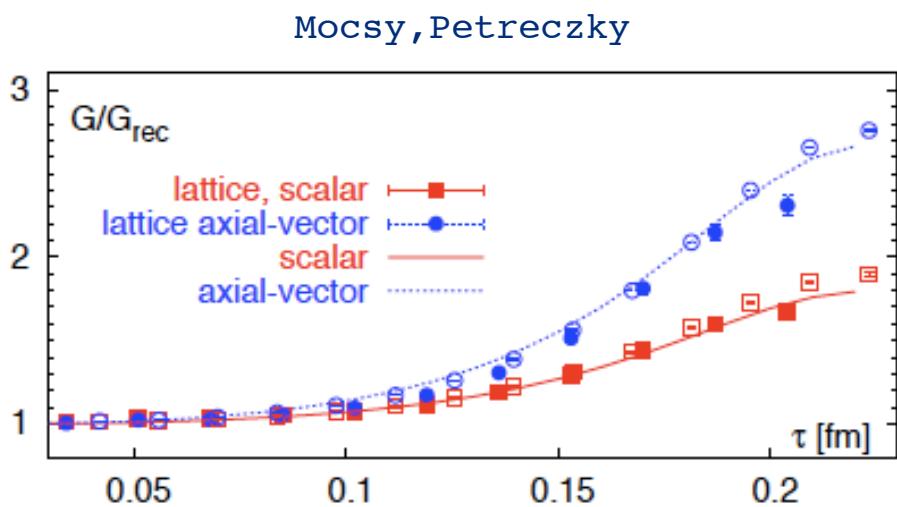


20% agreement

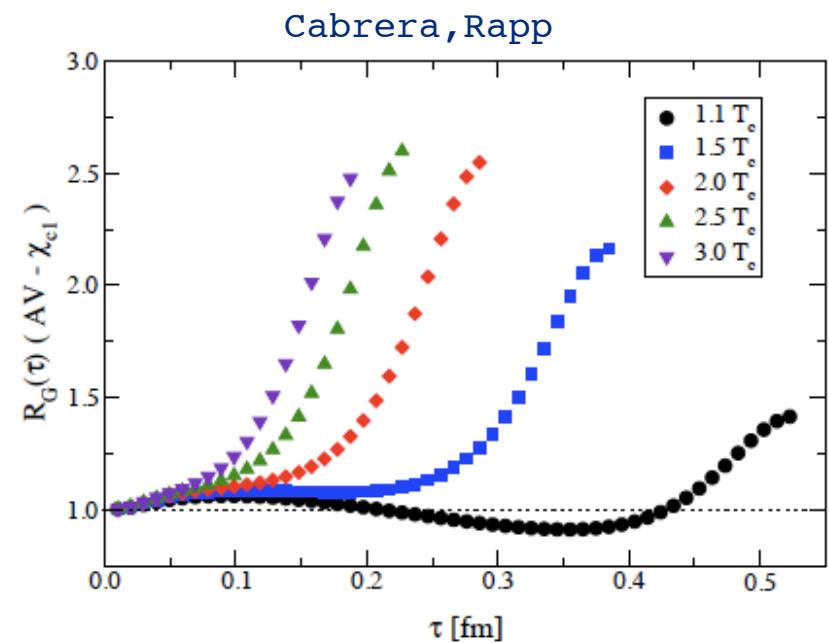
Bound states survive up to 2 Tc

Cabrera, Rapp

Compare the P-states



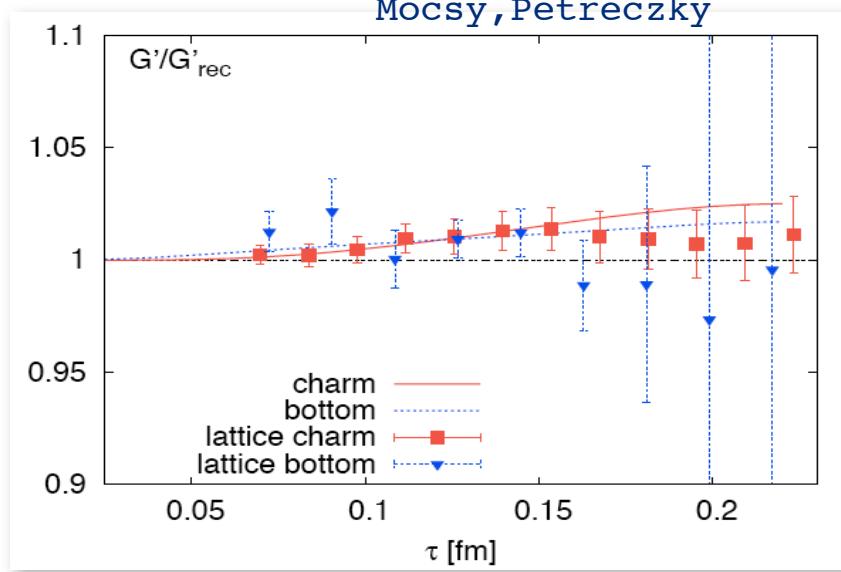
Quantitative agreement



Qualitative agreement

We understand that the increase in the correlator is due to zero mode contribution to the spectral function

Note on the P-states



$$\frac{G(\tau, T) = \int \sigma(\omega, T) K(\tau, \omega, T) d\omega}{G_{rec}(\tau, T) = \int \sigma(\omega, T=0) K(\tau, \omega, T) d\omega}$$

Correlator ratio (its derivative) flat up to high T also in the P-channels

Dissolution of the state does not show up in the temperature dependence of the correlator

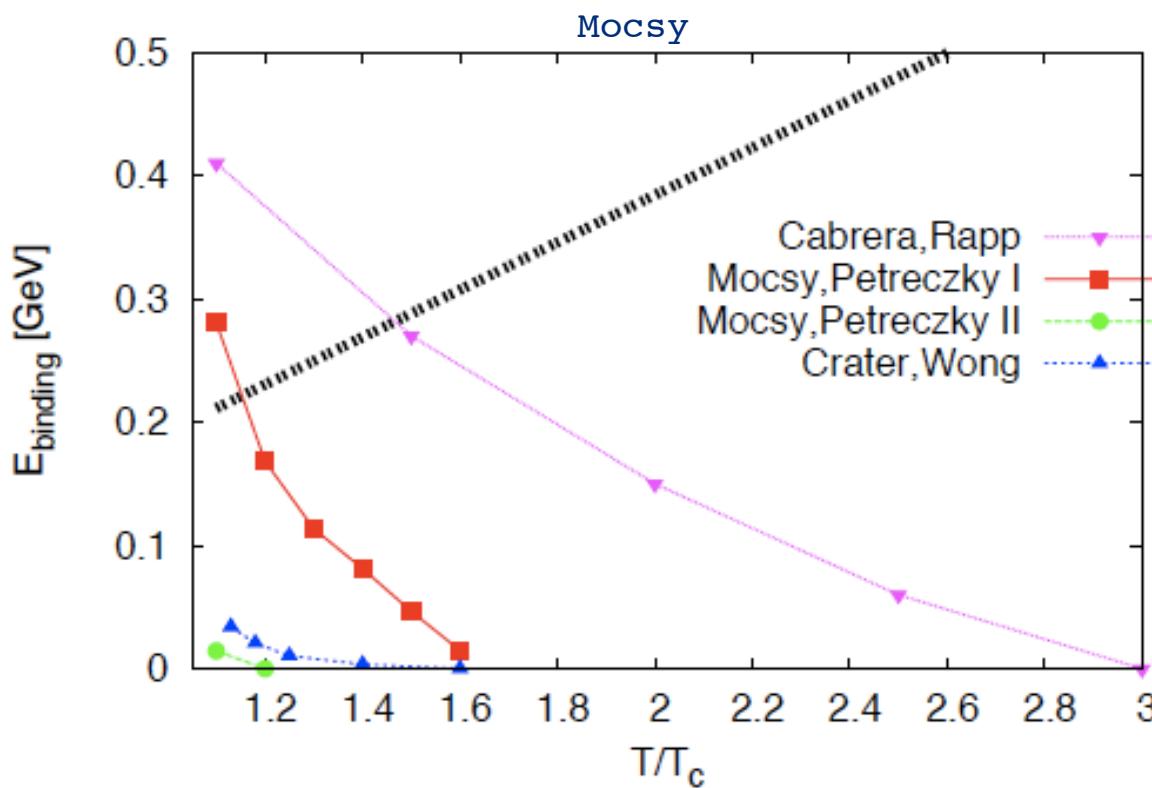
3(2)Tc versus 1.2Tc

Can we reconcile this?

3(2)Tc versus 1.2Tc

How can we reconcile this?

Jpsi Binding Energy vs Temperature

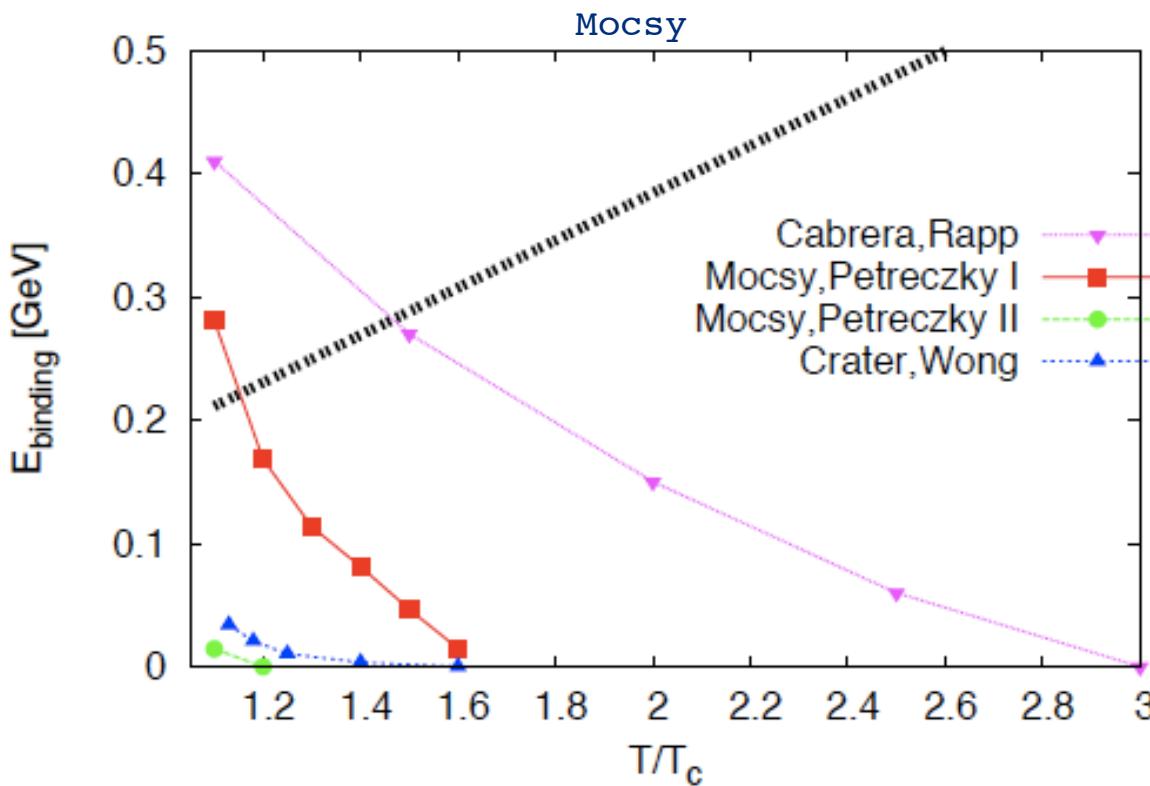


Dissociation condition

$E_{\text{bin}}=0$ $1.6 T_c$ vs $3 T_c$ \rightarrow Overkill

$E_{\text{bin}} \sim T$ expect substantial broadening due to thermal activation

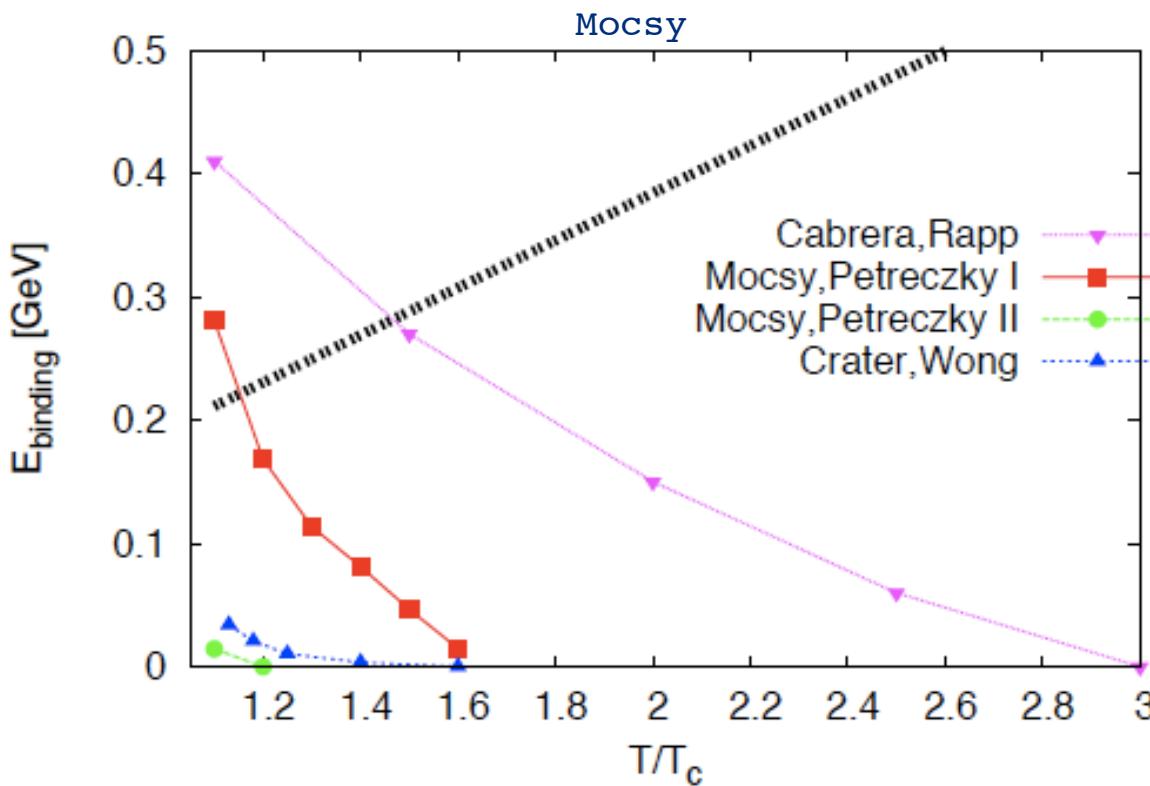
Jpsi Binding Energy vs Temperature



Dissociation condition

Ebin=0	1.6 Tc	vs	3 Tc	->	Overkill
Ebin~T	1.2 Tc	vs	1.5 Tc		

Jpsi Binding Energy vs Temperature



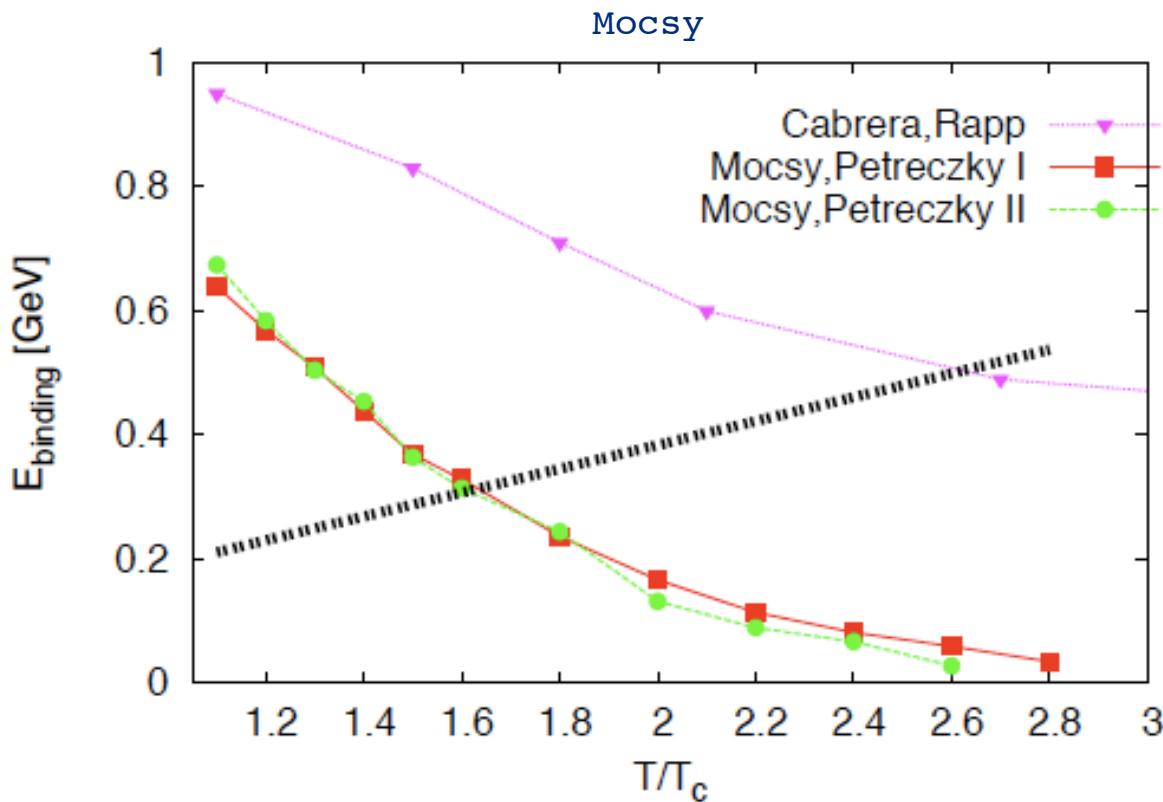
Dissociation condition

Ebin=0 1.6 Tc vs 3 Tc -> Overkill
Ebin~T 1.2 Tc vs 1.5 Tc

width \geq binding energy

“decays before it bounds”

Upsilon Binding Energy vs Temperature



- bigger discrepancy -

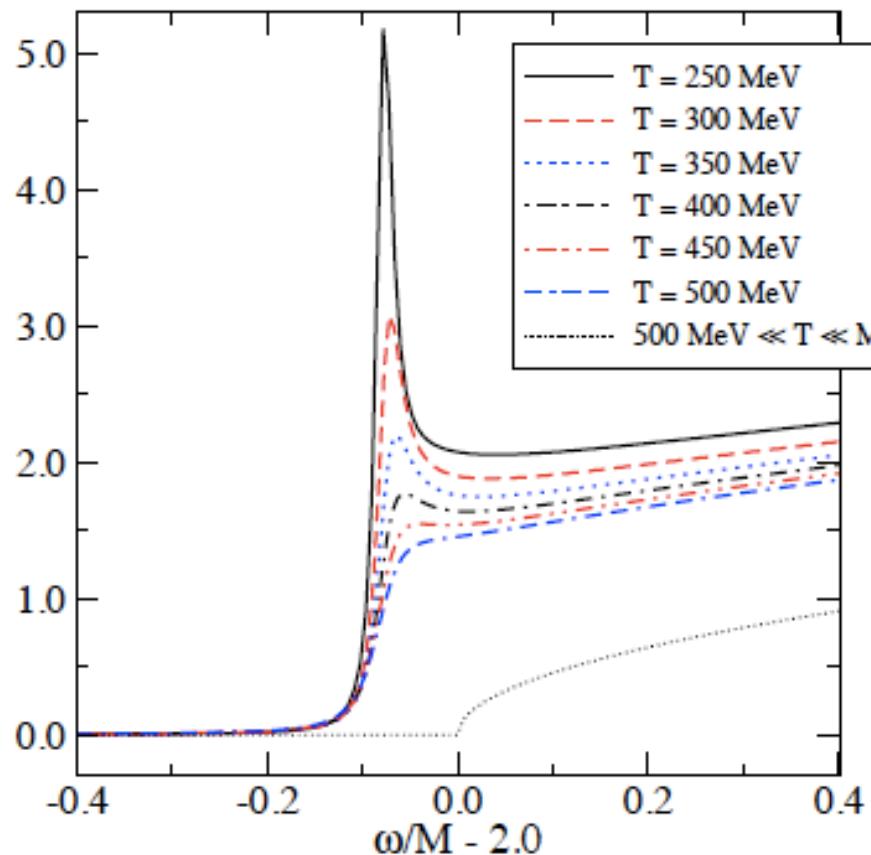
can be understood from the fact that the upsilon sits deeper in the potential, making short (intermediate) distances relevant

see also discussion in Dumitru et al, PRD 2009

Bound State Broadening

bottomonium

Laine



Quarkonium potential has Real & Imaginary part

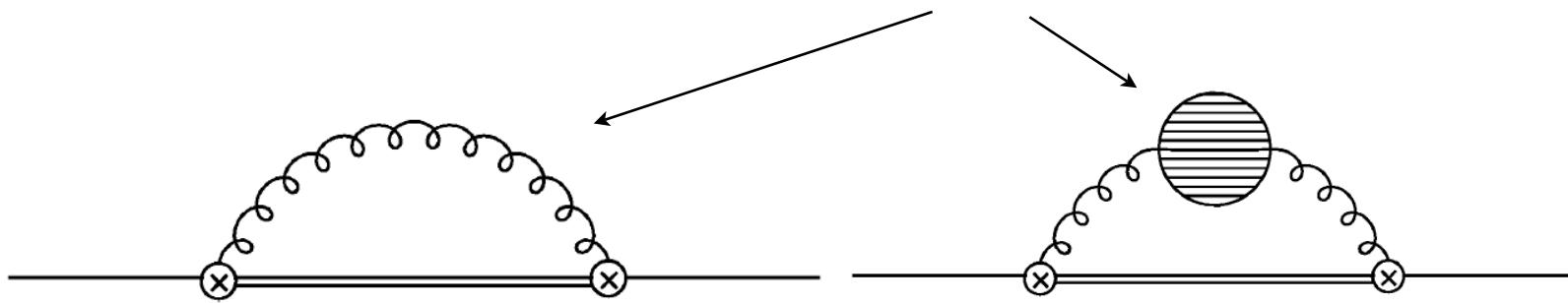
Discovery from new EFT calculations: Quarkonium potential has Real & Imaginary part

Re $V_S(r,T)$

part

Im $V_S(r,T)$

thermal width of QQ



octet transition

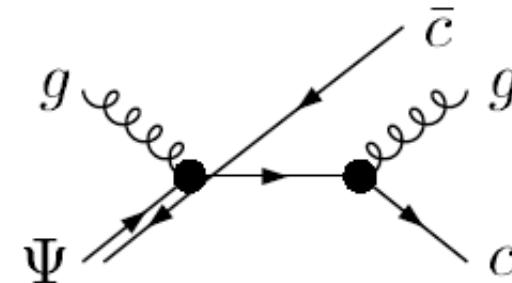
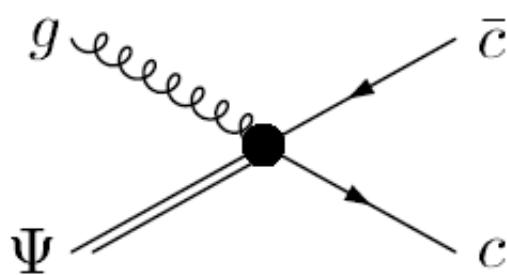
Landau damping

thermal breakup of a Q-Q
color singlet into a color
octet state and gluons

gluon self-energy,
scattering of particles in the
medium with space-like
gluons Laine, 2007

Brambilla, Vairo, Petreczky 2009

Bound State Broadening



Grandchamp, Rapp
Park et al

We Need Im V !

**Potential models as applied until now are incomplete
neglect important medium effects**

Good news: Im V is easy to implement in Green's
function calculation

Will learn about the validity (domains)
of potential models

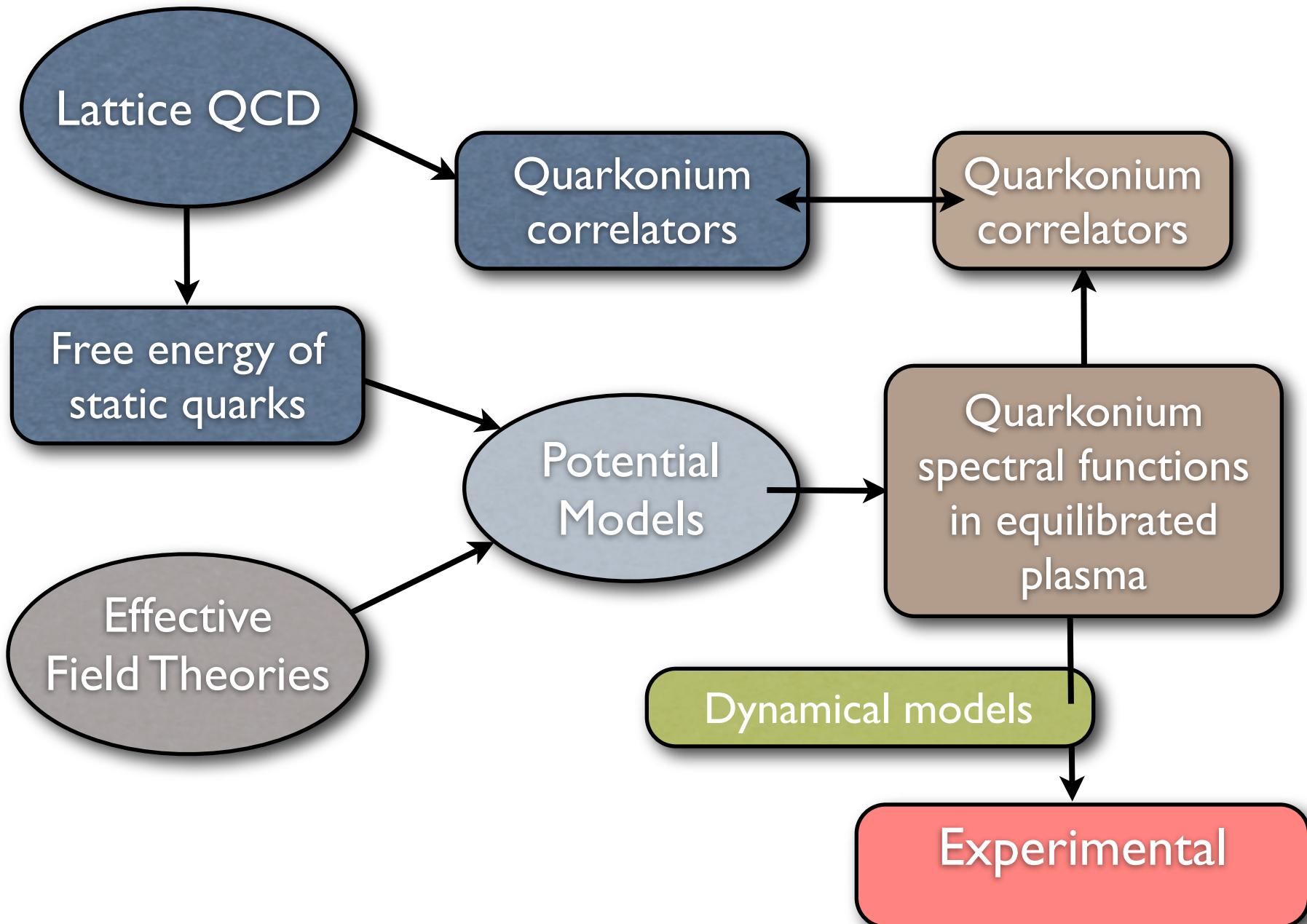
Bad news: Current effective field theory
calculations are only perturbative

Agree

- Threshold enhancement up to high T
- Decreasing binding energies with increasing T
- Increase in P-wave correlators due to zero modes

Disagree

- Quoted values of dissociation temperatures
- T-dependence of quark mass
- Potential (U vs Most confining) & Lattice data used
- Interpretation of lattice data



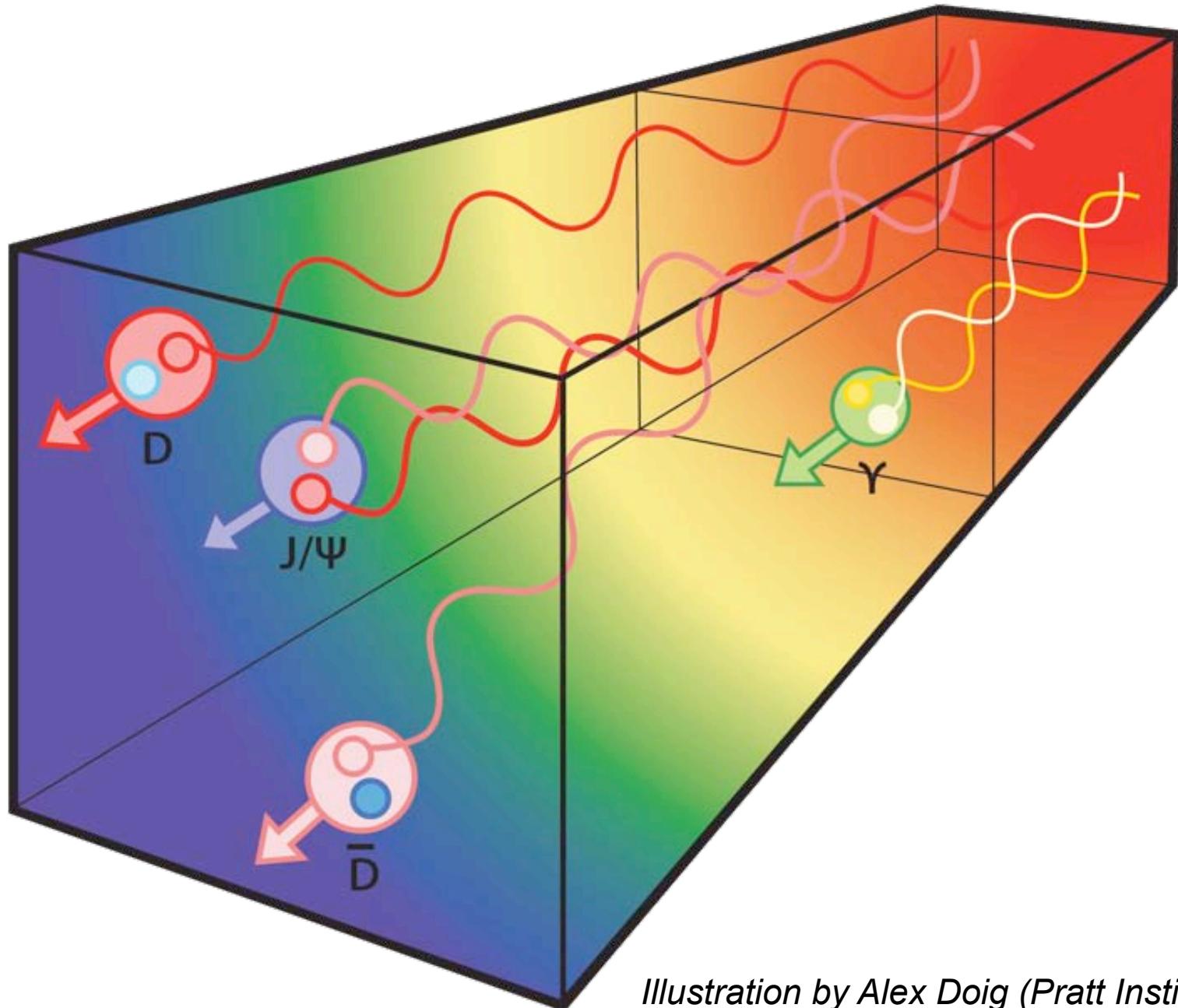


Illustration by Alex Doig (Pratt Institute)

THE END